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The Fleet Command Center Battle Management Program (FCCBMP) is an advanced technology prototyping effort introducing Expert System technology (e.g., rule based systems, artificial intelligence) into the Command Center of the Commander in Chief, U.S. Pacific Fleet. This paper discusses the application of advanced data base design methodology to an existing database supporting Expert Systems to ensure data consistency.

The objectives of the task were to (1) identify problem areas, (2) develop a conceptual model, (3) demonstrate the conceptual model using the FCCBMP database system, and (4) propose related research areas for further investigation.

Problem areas identified included: (1) lack of a well-structured design, (2) data requirements and consistency constraints were not well specified, and (3) the DBMS has difficulty in enforcing data integrity and consistency.

The Entity-Relationship model was successfully used to develop the conceptual model. Data abstractions proposed in other models were incorporated into the conceptual model as required.

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Additional research issues were identified: (1) expert system development for conceptual modelling, (2) unified representation of data and knowledge, (3) intelligent SQL, (4) time dimension in dynamic behaviors, (5) database validation and verification, (6) use of E-R methodology as a tool to migrate and integrate different Navy file and database systems in the Operations Support System (OSS), (7) development of a global schema for all databases in the distributed database systems using the E-R model, (8) development of an E-R-based DBMS which will allow a user to specify and enforce data consistency constraints, and (9) the use of the E-R model as the underlying model for a multimedia DBMS.

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An Entity-Relationship Approach to
Navy Command and Control
Conceptual Data Modelling
For Decision Support

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ABSTRACT

The Fleet Command Center Battle Management Program (FCCBMP) is an advanced technology prototyping effort introducing Expert System technology (e.g. rule based systems, artificial intelligence) into the Command Center of the Commander in Chief, U.S. Pacific Fleet. This paper discusses the application of advanced data base design methodology to an existing database supporting Expert Systems to ensure data consistency.

The objectives of the task were to (1) identify problem areas, (2) develop a conceptual model, (3) demonstrate the conceptual model using the FCCBMP database system, and (4) propose related research areas for further investigation.

Problems areas identified included: (1) lack of a well-structured design, (2) data requirements and consistency constraints were not well specified, and (3) the DBMS has difficulty in enforcing data integrity and consistency.

The Entity-Relationship model was successfully used to develop the conceptual model. Data abstractions proposed in other models were incorporated into the conceptual model as required.

Additional research issues were identified: (1) expert system development for conceptual modelling, (2) unified representation of data and knowledge, (3) intelligent SQL, (4) time dimension in dynamic behaviors, (5) database validation and verification. (6) use of E-R methodology as a tool to migrate and integrate different Navy file and database systems in the Operations Support System (OSS), (7) development of a global schema for all databases in the distributed database systems using the E-R model, (8) development of an E-R-based DBMS which will allow a user to specify and enforce data consistency constraints, and (9) the use of the E-R model as the underlying model for a multimedia DBMS.

EXECUTIVE SUMMARY

BACKGROUND

The Fleet Command Center Battle Management Program (FCCBMP) includes four applications derived from the CINCPACFLT Command and Control (C2) requirements:

- Force Requirements Allocation (FRESH)
- Capabilities Assessment (CASES)
- Operations Plan Generation (OPGEN)
- Strategy Assessment (STRATUS)

These applications represent the complete range of C2 functions and the decision making process. The applications are being developed at the headquarters of the Commander, U.S. Pacific Fleet (CINCPACFLT). Operational modules of FCCBMP provide battle management support for CINCPACFLT while development continues [13]. An accurate, timely, consistent database is vital to the application of expert systems to the C2 decision making process.

The Integrated Data Base (IDB) developed for the Operational Support Group Prototype (OSGP) using the Oracle relational Database Management System (DBMS), is the primary data source for the FCCBMP applications. The content and quality of the OSGP IDB was assumed to be adequate. The development plan was to incorporate data requirements for the applications as they were identified during the development. No top-down database design was considered necessary.

The development of the FRESH expert system required significant enhancement of the IDB to support all functionalities. It was soon discovered that the core IDB was seriously lacking in quality and accuracy. Database errors consistently invalidated the recommendations of the prototype expert system and often caused the system to crash. Errors were introduced from a wide variety of data sources (e.g. improper message formatting, incorrect spelling of unit names, missing data, or conflicting data) causing data ambiguity and inconsistency. Although the importance of data integrity enforcement was realized, no automated mechanism was available for the application developers and users to identify errors, prevent data inconsistency, and ensure data quality.

In the present Oracle DBMS used in FCCBMP, there are minimal built-in facilities provided for data consistency support. Users are forced to develop consistency checking as part of the application to maintain correctness of data. As the applications evolve, the consistency checking software must also evolve. Data integrity checking is incomplete since the applications only deal with a specific subset of the database at any one time and are not be aware of the overall semantics of the entire data base. Software developed to enforce a constraint may occur at several places which results in inefficiency as well as possible inconsistency.

In support of the FCCBMP project at CINCPACFLT, the Naval Ocean System Center (NOSC) proposed the Ashore Command Control Technology task under the Command Systems Technology Block Program sponsored by the Office of Naval Technology (ONT). One of the subtasks under the proposed work is Database Consistency. The specific goal of the Database Consistency task is to provide a consistent, responsive data base for the FCCBMP applications at CINCPACFLT.

DATABASE CONSISTENCY TASK SUMMARY

The scope of the Database Consistency task is to address the data base consistency issue, in general, using the FCCBMP data base as a case study for technology demonstration. The objectives are

- incorporate the knowledge of consistency constraints into the data base
- determine methodologies for data consistency assertions
- apply research results for implementation
- motivate related research areas

PROBLEM CATEGORIZATION

Several concerns regarding the FCCBMP database system have been expressed at CINCPACFLT: consistency, currency, quality, and quantity.

The FCCBMP database is implemented based on the relational data model [6][16] which is defined by its three components: a collection of object types, a collection of operators, and a collection of integrity rules. We follow these three basic constructs to examine the FCCBMP data base.

As the result of a quick survey of the FCCBMP system with primary focus on data consistency, the problems identified can be categorized in two major areas: data fragmentation and data inconsistency.

(1) Data Fragmentation

According to the relational model, all data are uniformly represented as tables. The relational model does not contain specific links between relations. Without a thorough understanding of the definition of the data base the relations appear to be merely a collection of data fragments.

The object types in the basic relational model are identified as relations and domains. The data items in the FCCBMP IDB schema were grouped into approximately 88 relations (tables) according to their functions or usage. Conceptually, most of these tables represent basic objects of interest as perceived by the users and applications. For example, the Track Position History (TRKPOS) relation is used to store historical positional information about

units (TRACKS).

The important semantics such as different types of objects and relationships between objects are not directly captured in the relational schema. The fact that the same domain name may have different semantics in different relations can cause semantic ambiguities in application processing. Implementation of the applications requires human understanding of the database structures and the semantics of the data. The missing semantics which are not directly supported by the relational data model can only be implemented in the application. The FCCBMP IDB does not reflect all the data requirements.

Although the relational model is a significant improvement over the more primitive record-oriented models, it still falls short of the key semantic features which are critical for the decision making and reasoning processes implemented in the FCCBMP applications.

(2) Data Inconsistency

Data consistency implies that all data values in the same data base are in agreement with each other. The data values must satisfy the constraints that are specified in the database schema. The basic constraints, according to the relational data model, are rules regarding the definition and usage of the primary key and foreign key, and the domains of the data. The primary key is not allowed to be null and the foreign key must match some already existing primary key. The permitted values for each data item are governed by the corresponding domain specified.

The relational model has an inherent difficulty in specifying and enforcing data consistency. Most of the relational DBMS, including the ORACLE DBMS used in FCCBMP, do not provide direct support for the basic required integrity rules.

Four types of redundancy occurred in the IDB which led to inconsistency between related pieces of data. First, multiple copies of data were kept in different locations in the data base. Second, many data items were derived from other data items through computation. Third, synonyms (the same data item is referred to by different names) and homonyms (the same name is used for different data items) were used in the data base. Finally, data items were restructured for different purposes which presented semantic inconsistencies.

APPROACH

The problem of maintaining data consistency is divided into three issues to be examined: data requirement specification, constraints specification, and constraints enforcement. Specific technologies were proposed to examine each issue.

In this paper, we will only cover the investigation and findings

of the data requirement and consistency constraints specification issue.

A data modelling based on the Entity-Relationship (E-R) Model approach [2] was used to establish the FCCBMP conceptual data model. The same approach is being used to model the consistency constraints.

ENTITY-RELATIONSHIP MODEL

The E-R approach is based on the E-R Model and it's extensions [3]. The E-R Model is an object-oriented semantic data model which formalizes the fundamental concept of entities and relationships as the building blocks to describe an organization's information structures.

Within the E-R framework, the information structures are viewed as consisting of four basic components: ENTITIES, RELATIONSHIPS, ATTRIBUTES of entities or relationships, and VALUES.

Entity types are associated by the relationship between them. Relationships can be classified into relationship types which may have descriptive attributes. How entity types are related to each other is expressed by the four types of mapping cardinality: one-to-one, one-to-many, many-to-one, and many-to-many. These mapping constraints define the number of entities of one entity type that can be related to other entities of another entity type via a relationship. They are important consistency constraints [12].

The E-R Diagrammatic technique which uses a graphical notation to express the concept of entity, relationship, and their properties, provides a powerful tool for communication between decision makers, system developers, users, and non-computer people.

Existing and proposed translation rules to convert the E-R Model to conventional data models (e.g. relational, network, hierarchical) have demonstrated the E-R Model can be used as a basis for unification of different views of data.

In the following section, we summarize the FCCBMP conceptual data modelling process.

FCCBMP CONCEPTUAL DATA MODEL

The existing data base was developed in a fragmented manner to satisfy specific functional requirements. No global view of the data and their structures is available. Database developers and users have to make assumptions about the overall logical structure or usage of the data. These assumptions often lead to data inconsistency and a degradation of decision-making capability.

The primary goal of the FCCBMP conceptual data modelling is to provide a global view of the data for applications development using the E-R methodology.

Following the "top-down" process of the E-R approach [10], we modelled the real world in two levels: upper-level and lower-level.

(1) Upper-Level Modelling

The first step of the upper-level modelling was to identify the objects of interest and the relationships among them represented in the E-R Diagram. The Navy Warfare Publication Library, FCCBMP Functional Description, and FCCBMP Data Dictionary were the primary source documents. CINCPACFLT representatives, the FCCBMP team members, and the NOSC Marine liaison were consulted to refine concepts. Figure 1 depicts the overall FCCBMP conceptual data model [1][4].

The next step was to examine the intra and inter relationships among the entity and relationship types using the concepts of aggregation [15], generalization, and specialization abstractions.

(2) Lower-Level Modelling

The first step of the lower level modelling was to identify the properties of entities and relationships which are of interest to FCCBMP and CINCPACFLT. We used the content of the existing IDB to determine the list of attributes. One or more of the attributes of the entity were designated as the entity identifier which uniquely identifies the entity. Future FCCBMP data requirements have been and will continue to be identified through the conceptual data model.

FRAMEWORK FOR CONSISTENCY CONSTRAINTS CLASSIFICATION

A preliminary framework [5] for classifying the consistency constraints independent of an underlying data model is established based on the generic components of data models: (1) data element: the lowest level building block; (2) basic information units: the "container" of data elements; (3) high level information unit: an aggregation of basic information units.

The consistency constraints are then classified as: (1) constraints on each data element, (2) constraints between data elements within the same basic information unit, (3) constraints between two or more basic information units, (4) constraints on the composition of basic information units to higher-level information units, and (5) constraints between the information units on the same level and different levels.

Most of these constraints are embedded in or can be inferred from the E-R model. The commonly used constraints in the relational

model such as domain constraints, primary and foreign keys, functional dependencies, multi-valued dependencies, and referential integrity are also captured in the model.

These constraints governing the definition and values of the data need to be shared similar to the way that the data in the database is shared among applications. The first issue is to establish a mechanism to model the consistency constraints. Secondly, we need to provide a methodology for the users to derive a "complete" set of consistency constraints.

CONCLUSIONS

The conceptual data model [17] reflects the generic aspects of the information and flow required to support decision making as perceived by CINCPACFLT and consequently the expert systems being developed to assist decision makers. The model provides a unified conceptual view of the data allowing decision makers, system developers, and system users to better communicate their ideas. The model is the framework for the current design of the FCCBMP database and the continuing investigation of the data consistency issue.

(1) E-R TECHNOLOGY FOR NAVY APPLICATIONS

The E-R approach has been successfully used for the FCCBMP conceptual data modelling for the database initial design. The conceptual model is a prerequisite for the investigation of the consistency constraints specification issue.

(2) DATA CONSISTENCY

Data consistency is essential to any database development. Existing DBMSs fail to allow the user to specify and enforce data consistency constraints, which are vital in the decision making in the Navy C3 environment. A methodology must be established for consistency constraints specification as part of future DBMS development.

(3) OPERATIONS SUPPORT SYSTEM (OSS) C2 DATABASE

Migration of a file-based system to a DBMS-based system, or from one DBMS to another DBMS requires a blueprint to ensure that the integrity of the database structure is maintained. The "reverse engineering" [7][8] of the E-R approach can be used to develop a conceptual data model on the existing files used in the system, and then used to generate the schema for the OSS DBMS.

(4) MULTI-MEDIA DATA MANAGEMENT

The use of unformatted multi-media data (e.g. graphical, tabular, textual, image, voice, etc.) is required to support decision making in a complex world. The full implementation of the conceptual model will require support for both formatted and unformatted data which calls for additional technology

requirements.

CURRENT EFFORT

The current efforts include:

(1) Extension of the lower-level modelling to investigate the consistency specification issue.

(2) Translation of the E-R based FCCBMP conceptual data model to the relational schema to be used to define the IDB relations.

FUTURE EFFORTS

Future efforts will proceed with the investigation of the data consistency issue based on the conceptual data model. The immediate task is to assess a mechanism for consistency constraints specification. This specification will then be used as a guideline for prototyping a constraints enforcement facility.

RELATED ISSUES

Several research issues related to conceptual modelling have been identified during this task:

(1) Unified framework for database and knowledge base systems

Data in current database systems and knowledge in expert systems use different representations. When information is needed, data and knowledge need to be transformed from one representation into another representation. While decision-making requires all facts and knowledge about the subject, there is a strong need to integrate data and knowledge. A unified representation of data and knowledge is necessary.

Recent research results [11] have shown that the E-R approach can be used as a unified framework for both database and knowledge base systems. A set of translations rules for the implementation of E-R diagrams in first-order logic, frame-based, and production systems is provided.

(2) Dynamic behavior and time dimension

The time-dependent information [9] and the dynamic characteristics [14] of the system need to be incorporated into the conceptual model.

(3) Database validation and verification

Currently, there is no mechanism available to verify the correctness of the data in the database. It is intended that the mechanism established in this task for constraints specification and enforcement can be used for the verification and validation of the database.

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FCCBMP NAVY CONCEPTUAL MODEL

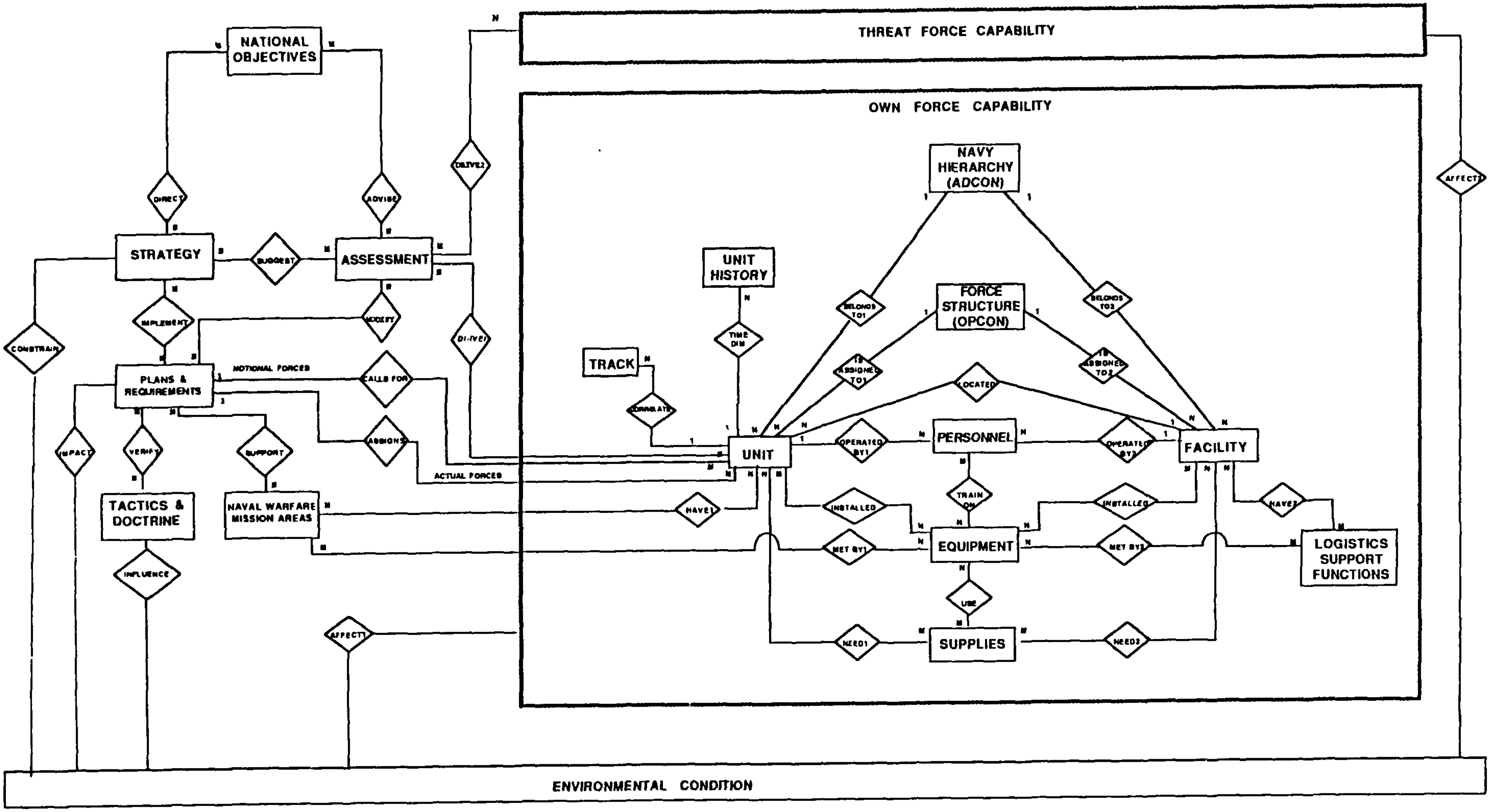

Figure 1